AN INTERIM PROGRESS REPORT TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

INFRARED SPACE OBSERVATORY (ISO) DATA ANALYSIS

UNIVERSITY OF HAWAII BLOCK GRANT

Robert D. Joseph
Administrative Principal Investigator
University of Hawaii at Manoa
Institute for Astronomy
2680 Woodlawn Drive
Honolulu, HI 96822

Period Covered:
ISO Fiscal Year 4
15th August 1998 through 14th August 1999

1) "THE ISO CENTRAL PROGRAMME NORMAL GALAXY SURVEY"

Robert D. Joseph
Principal Investigator

BACKGROUND

Joseph is an ISO Co-Investigator. His Guaranteed Time Observations include both a major programme for which he is the Principal Investigator, and a number of other programmes in collaboration with other ISOPHOT Co-Investigators.

Joseph's major research interest using ISO, and the ISO Guaranteed Time Observing program for which he is Principal Investigator, is the "ISO Central Programme Normal Galaxy Survey." It is a complete and unbiased survey of an optically-selected, magnitude-limited sample of ~100 spiral galaxies. The sample was taken from the Revised Shapley-Ames Catalogue, with a magnitude limit $B_T = 12$. The measurements includes imaging at ~12 μm using ISOCAM, and photometric imaging using ISOPHOT at ~60 μm, ~100 μm, and ~185 μm. Joseph has also obtained complementary J, H, & K imaging using ground-based telescopes. Additional ground-based observations in the sub-millimeter spectral region (450 μm and 850 μm) are beginning, and there is radio HI and optical imaging already available for most of the sample. When completed this will be the most complete catalogue of infrared observations of a complete sample of normal galaxies ever obtained. It should become a major research resource for astronomers for the next decade.

PROGRESS

The ISOPHOT Interactive Analysis (PIA) software and the ISOCAM Interactive Analysis software have been installed at the Institute for Astronomy and are continuously upgraded with the latest releases of this software in Europe.

Both the ISOPHOT data and the ISOCAM data for the sample have been completely reduced. The Research Assistant on this project, Mr. George Bendo, has successfully passed his Ph.D. Qualifying Examination and has taken this project as the core of his Ph.D. thesis project.

A significant part of the work this past year has been to test the reliability of the ISO data reduction and calibration, which has continued to be a worry for ISOPHOT. A variety of analyses, including comparisons with data from the IRAS and COBE spacecraft for both the target and background data, have led to our conclusion that the ISOPHOT data reduction is reliable for the integrated photometry from the C100 and C200 arrays. However, a potential key advantage of the ISO measurements should be ability to obtain diffraction-limited angular resolution at 60 μm and 100 μm. This requires excellent flat-fielding of these two arrays, and this is not yet available. A major improvement in the calibration and flat-fielding algorithms in

the ISPHOT Interactive Analysis software is expected to be released in August '99, and this should enable us to fully exploit the potential advantages of the ISO data.

Two manuscripts have been written on the first results of analysis of these ISO data. They are currently undergoing revision, but will be submitted for publication as soon as is practicable. (They must be circulated to about a dozen European collaborators for their approval before being submitted .)

An extensive program of complementary ground-based observations has also begun. These observations will provide significantly enhance the scientific interpretation of the ISO results. The two programs are: a) submillimeter imaging at 450 μm and 850 μm of a sub-sample of the ISO program galaxies, and b) near-infrared spectroscopy of the entire sample. The former enormously strengthens interpretation of the ISO 185 μm data and bears especially on the accumulating arguments that ISO finds a new and very cold component of interstellar dust in galaxies. The latter program will provide quantitative diagnostics of recent star formation activity and the resulting stellar population which are the putative energy sources for the ISOPHOT and ISOCAM photometry.

PLANS FOR ISO FISCAL YEAR 4

The major objectives for this year are as follows.

a) Major effort will go toward obtaining reliable diffraction-limited angular resolution from the ISOPHOT data. As noted above this has not be possible up to now, but this should be possible with the next major release of the ISOPHOT Interactive Analysis software currently scheduled for release in August '99.

b) The second area of major effort will be in doing the ground-based observations which are so important to enrich the scientific interpretation of the ISO data on this galaxy sample. Observing time has already been awarded on the James Clerk Maxwell Telescope for the submillimetre observations and on the NASA Infrared Telescope Facility (IRTF) for the near-infrared spectroscopy. A new spectrometer for the IRTF will be commissioned in January; this is ideally suited for the spectroscopy requirements for the ISO galaxy sample and it will enable us to take the required data at much high efficiency and spectral resolution than was possible heretofore.

c) We expect this to be a year in which we are finally able to see the ISO data reach scientific fruition. After considerable effort to analyze, re-analyze, check and double-check the data reduction and calibration for accuracy and reliability, several publications based on the ISO data should appear.

Travel proposed in Year 4: i) Bendo will present a paper and participate in an ISO workshop entitled "ISO Beyond Point Sources: Studies of Extended Infrared Emission." It will be held at

the ISO Data Centre in Villafranca (near Madrid), Spain in mid-September. While in Europe, Bendo will also spend a few days working at the ISOPHOT Data Centre in Heidelberg, Germany. ii) Joseph will present a paper and participate in an ISO workshop entitled "ISO Surveys of a Dusty Universe" to be held at Ringberg Castle in Germany in November. iii) Joseph also hopes to be able to attend the next ISOPHOT Consortium meeting, which is usually held in Heidelberg, Germany. He also has a large number of European collaborators on the "Normal Galaxy" program, and he is a collaborator on a number of other ISO projects. He expects to make one or two trips to Europe this year to meet with these collaborators to work out data analysis problems and work on joint papers.

2) "JOINT U.S.--JAPAN OBSERVATIONS WITH ISO: DEEP SURVEYS AND OBSERVATIONS OF HIGH-Z OBJECTS"

David B. Sanders
Principal Investigator

PLANS FOR ISO FISCAL YEAR 4

We are currently re-reducing our ISOCAM LW2 survey data on the Lockman Hole NW and SSA13 deep fields using the final version of the CAM analysis software package that has been recently updated by the CAM team both at Saclay (Paris) and at Vilspa (Spain). This task is expected to be complete by end of Spring Y2000. The final ISOCAM cleaned maps will then be compared with the deep optical and near-infrared images that were obtained this past year with the 8Kx8K array on the UH 2.2m telesope. A final paper summarizing the identified sources in both fields will be written in early 2000. A second paper summarizing the redshift results will most likely be written in mid-to-late-2000 depending on the success of Keck spectroscopy in the Spring-2000 semester.

Work is proceeding on identifying the counterparts of the ISOPHOT 90 μm and 175 μm sources detected in the LH-Rosat and LH-NW deep fields. Positional uncertainties of typically 40" make it impossible to pinpoint the true optical counterpart (hence obtain redshifts) for these sources. Kawara et al. have identified nearly 80 sources at 175 μm in the two 44'x44' fields. Observations are currently proposed for the VLA-B configuration in late 1999, and are ongoing with SCUBA (at 850 μm) on the JCMT in order to locate the source positions to better than 1 arcsecond. Spectroscopy will then be proposed with either CFHT or Keck (depending on the brightness of the counterpart at optical and/or near-infrared wavelengths) during the Spring2000 semester. We hope to be able to submit a paper summarizing the initial identifications and spectroscopic follow-up by late Y2000.

3) "CORRELATIONS BETWEEN FAR-INFRARED SPECTRA AND QSO HOST GALAXY MORPHOLOGY"

Alan Stockton
Principal Investigator

BACKGROUND

From IRAS data, we have identified a possible correlation between QSO far-infrared (FIR) spectral-energy distributions and host galaxy morphologies. If confirmed, this correlation will be important in understanding the evolutionary history of the QSO phenomenon. Basically, we find that, of a sample of 34 QSOs with good detections by IRAS at 25, 60, and 100 μm, the three that fall close to the region of the FIR two-color diagram occupied by the ultra-luminous starburst galaxies are also the three QSOs having host galaxies showing convincing tidal tails. We are attempting to test this correlation by observing a sample of QSOs at higher redshift with ISO. Because of the size of our allocation of ISO time and changes from the original sensitivity estimates, we have had to decrease the size of our sample fairly drastically, so the emphasis is now more on a study of a few individual objects.

PROGRESS DURING THE PAST YEAR

The PI (Stockton) spent a week at IPAC in June, 1998, and worked on both the ISOPHOT and ISOCAM observations with the help of IPAC staff. Satisfactory reductions of the ISOCAM images were completed during this period, but no clear detections were made from the ISOPHOT data. The PI was advised to wait until improvements were made to the ISOPHOT reduction procedure and then to try again.

One attempt was made to obtain ground-based images in support of the ISO program, but weather conditions were unfavorable, and no images were obtained.

REQUEST FOR NO-COST EXTENSION FOR ISO FISCAL YEAR 4

On the advice of Nanyao Lu at IPAC, we have delayed further efforts to reduce our ISOPHOT data until a deeper understanding of the detector characteristics resulted in improved reduction procedures. It is our understanding that a new version of ISOPHOT Interactive Analysis software with significantly improved flat-fielding procedures will be released within the next few months. We request a no-cost extension for one year in order to take advantage of these improvements.

4) "EXTREMELY RED GALAXIES AND SEARCH FOR PRIMEVAL GALAXIES AROUND Z~4 QUASARS"

Esther Hu
Principal Investigator

BACKGROUND

The sponsored ISO research investigates highly reddened and potentially early galaxies in high redshift (z~4) quasar fields, and includes observations of one of the most highly dust-reddened, ultra-luminous infrared galaxies known (Hu & Ridgway 1994).

PROGRESS

The existing ISOCAM and ISOPHOT observations have only provided upper limits on galaxy spectral energy distributions at 7 μm and 175 μm for the two brightest ultrared objects in this field. The PI (Hu) visited IPAC in April 1999 and consulted with IPAC staff about optimizing the reductions. This is most likely to yield positive results for the ISOPHOT 175 μm observations with new processing software. Deep red optical and near-IR images on this field have been obtained with the Keck 10-m telescope and the UH 2.2 m telescope, and these show an excess of very red, but fainter galaxies in this field. Efforts to improve sensitivity of the ISOCAM detections by adding in archival observations have begun, and are described below in plans for upcoming work. Redshift determination through IR spectroscopy at UKIRT was attempted for one of the ultrared sources, but in the absence of strong emission lines a determination could not be obtained for such a faint source from a 4-m telescope.

PLANS FOR ISO FISCAL YEAR 4

We hope to improve the sensitivity of the results by combining our ISO data with newly available ISO archival observations to obtain detections of dusty galaxies in the quasar field. We are pooling the ISOCAM data with a similar survey of this region by the ISOCAM group at Saclay (in a collaboration begun with David Elbaz). This will increase the sensitivity for the brightest ultrared objects that were selected on the basis of deep red optical (0.84 μm) and near-IR (2.1 μm) images. In addition we hope to learn whether there is an overall statistical excess in detected flux associated with fainter extremely red objects found across the wider field included in their scans. A reanalysis of the ISOPHOT data with new reduction software will also be undertaken. We also hope to use the IR spectrograph (NIRSPEC) that has just become available on the Keck 10-m telescope for investigating these objects in upcoming time this semester.

PUBLICATIONS

"ISO Deep Far-Infrared Survey in the Lockman Hole," Kawara, K., L., Sato, Y., Matsuhara, M. Taniguchi, Y., Okuda, H., Sofue, Y., Matsumoto, T., Wakamatsu, K., Karoji, H., Okamura, S., Chambers, K.C., Cowie, L.L., Joseph, R.D., Sanders, D.B. 1998, Astron & Astrophys, 336, L9.

A Study of the Spatial Fluctuations of FIR Brightness in the Lockman Hole, H. Matsuhara, K. Kawara, Y. Sato, Y. Taniguchi, H. Okuda, T. Matsumoto, Y. Sofue, K. Wakamatsu, L. Cowie, R. Joseph, D. Sanders, in "The Universe as Seen by ISO", in press (1999).

Deep Submillimeter Surveys: Luminous Infrared Galaxies at High Redshift, D.B. Sanders, in "Space Infrared Telescopes and Related Science, eds. T. Matsumoto and T. deGraauw, Ad. Space Research, in press (1999).

(BOOK) "Galaxy Interactions and Low and High Redshifts", eds. J.E. Barnes and D.B. Sanders (Dordrecht: Kluwer), 548pp. (1999) (OSBN 0-7923-5832-5).

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Robert D Joseph, David B Sanders, Alan Stockton, Esther Hu

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University of Hawaii Institute for Astronomy
2680 Woodlawn Dr.
Honolulu, HI 96822

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